Mineralogical and Chemical Significances of Modern Marine Sabkha, Developed in the Southern Corniche Beach of Jeddah, Red Sea Coast

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Abstract

A combination of field work, mineralogical and geochemical analyses have been used to study the characteristics of the supratidal flat sabkhas developed on the southern Corniche of Jeddah. Mineral significances of sabkha deposits are considered a guide for understanding the mode of formation while, study of the chemistry of sabkha reflects the diagenetic history and pollution. Gypsum, halite, aragonite, Mg-calcite, quartz and feldspar are the dominant minerals present while, calcite, dolomite, amphibole and pyrite occur in small amounts. Significant vertical alteration of both carbonate and evaporite minerals with depth are noticed in the studied sabkha sequence. Distribution of elements (iron, manganese, copper, zinc and lead) in the sabkha sediments from four holes indicates characteristic differences. The downward increase of Fe concentration in sabkha sequences can be related to diagenetic processes, while enrichment of Cu, Zn and Pb are related to a pollution of the area due to dumping untreated municipal sewage and industrial waste in the sea.

Keywords

Supratidal Flat; Sabkha; Total Minerals; Diagenesis; Chemistry; Pollution

Introduction

The Southern Corniche of Jeddah is described as a low-lying and almost flat coast (Fig.2). It is occupied mainly by many random pools with restricted marine water supply and/or open supratidal environment with unrestricted and continuous hydrodynamic flow regime with saline ground water table formation. The brines get into the sediment by continuous subsurface seepage. Both types of coastal sabkhas are mainly characterized the Southern Corniche of Jeddah. An active sabkha is underlain by porous sediments that supply groundwater as well as marine waters to keep pace with the water lost through evaporation at sabkha surface. The Southern Corniche of Jeddah is occupied by hard coral reefs covered by biogenous sandy sediments with different thickness. Inshore, sabkha defined as a supratidal flat surfaces formed by back precipitation for marine sediments (Kinsman, 1969). Sabkha was formed in an arid region where evaporation greatly exceeded precipitation. Sabkha is effectively developed when subsurface sediments with high porosity feed the sabkha on the surface from under-ground water which can rise by capillary action (Fig.3). The sabkha environment is accompanied by the formation of high temperature minerals. Recent coastal marine sabkhas in many regions such as the Arabian Gulf sabkhas are considered active environments for the accumulation of trace elements. In fact little attention had been devoted to the Red Sea sabkhas of the western coast of Saudia Arabia compared to the Arabian Gulf and Gulf of Aqaba (El-Sayed, 1987; Behairy et al, 1991; Basyoni, 1996). Ras Hatiba sabkha follows the Gavish sabkha model, where aragonite and gypsum disappear under certain environmental conditions. Gavish et al (1985) related the removal of gypsum by sulphate reducing bacteria.

A comparison study between Shuaiba and Sharm el-Kharrar sabkhas south and north of Jeddah made by Gheith (1999) proved different composition and origin. Shuaiba sabkha had a carbonate dominated minerals with high potential dolomitization and evaporate association compared to Sharm el-Kharrar which is considered a siliciclastic sabkha with abundance land derived materials affecting the sedimentation regime. This kind of sabkha similar to Al-Lith sabkha studied by Basyoni (1996).

The Southern Corniche of Jeddah has not been exploited until now and is considered to be storage for municipal sewage and industrial waste. The aim of the present research is to determine the mineral and chemical characteristics of sabkhas deposits in the Southern Corniche of Jeddah.

Geomorphology of the Jeddah Coastal Area

Jeddah is located in the middle part of the eastern Red Sea coast where the continental shelf and coastal plain widen to a distance of about 15 km. Jeddah was developed by infilling the swamps and was subdivided into Northern Corniche and Southern Corniche (Fig.1). The external continental shelf is mainly composed of a coral reef platform covered with thin layer of biogenous carbonate sediments. The development of coral reefs have affected Jeddah city, where the morphology is clearly observed as longitudinal coral reef bars parallel to the beach and are separated by deep water. Shoreward the shelf rises about 1 m high of hard consolidated coral reef. However, many lagoons were developed in the low-lying land shoreward. The composition of the inland Quaternary coralline limestone indicates deposition in a regression sea under high energy conditions (Basaham, 1998).

Sample Collection and Analysis

Sabkha sediments were sampled from the upper 60 cm of the supratidal flats from four short holes made near the lagoons formed in the Southern Corniche of Jeddah (Figs.3&4). Twenty samples were collected using a small grab sampler. A small portion of dried samples was powdered in an agate mortar and then passed through a 0.063 mm sieve and mounted in a glass slide. Total mineral constituents of the samples were determined using X-ray diffraction method. Slides were run at rate of ½°minute through the interval from 10° 2θ to 50° 2θ using copper radiation. Mineral identification was based on the table of key lines listed by Chen (1977). The peak height of the biggest intensity for each mineral present has been measured and summarized in Table (1).The relative percentages of each mineral have been calculated according to Carver (1971) and Milliman (1974). A portion of each raw sample was subjected to digestion with HNO_3 and HF. Measurements of elements (Ca, Mg, Fe and Mn, Zn, Cu and Pb) were determined by an Atomic Absorption Spectrophotometer.

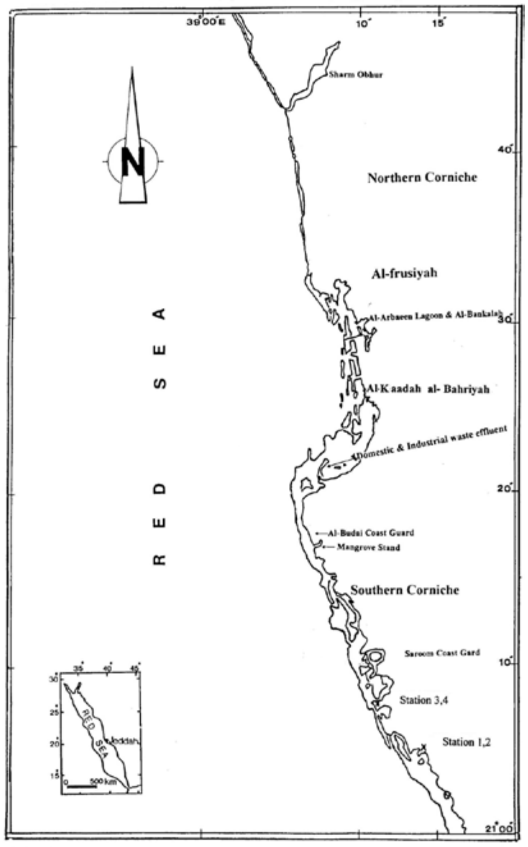

FIG. 1 MAP OF JEDDAH COASTAL AREA SHOWING LOCATION OF SABKHA SAMPLING STATIONS IN THE SOUTHERN CORNICHE BEACH

FIG.2 WIDE FEATURELESS LOW-LYING COAST WITH DEVELOPED LAGOONS ON THE SOUTHERN CORNICHE OF JEDDAH

FIG.3 SUPRATIDAL FLAT SEDIMENTS WITH FORMATION SALT CRUST DUE TO STRONG EVAPORATION OF THE RISING UNDERGROUND WATER BY CAPILLARY ACTION

FIG.4 HOLE MADE IN THE SABKHA SEDIMENTS. NOTICE CLAY RICH WITH ORGANIC MATTER

FIG.5 HOLE MADE IN WETTED SABKHA NEAR THE LAGOONS. NOTICE HIGH ACCUMULATION OF ORGANIC MATTER FORMED IN ANAEROBIC ENVIRONMENT

TABLE (1) X-RAY DIFFRACTION MEASUREMENTS OF DETECTED MINERALS IN THE ANALYZED SABKHA SEDIMENTS.

				Evaporate Minerals				Carbonate Minerals								Terrigenous Minerals									
				Gypsum		Halite		Aragonite		Calcite		Mg-Calcite		Dolomite		Quartz		K-Feldspar		Plag-Feldspar		Amphiboles		Pyrite	
S.No		Sample	Depth (cm)	2θ	d(Å)	2θ	d(Å)	2θ	d(Å)	2θ	d(Å)	2θ	d(Å)	2θ	d(Å)	2θ	d(Å)	2θ	d(Å)	2θ	d(Å)	2θ	d(Å)	2θ	d(Å)
1	Hole -1	1	Surface	11.7	7.56	31.7	2.82	----	----	----	----	----	----	----	----	26.6	3.35	23.4	3.80	28	3.19	----	----	----	----
2		2	1-20	11.7	7.56	31.7	2.82	----	----	----	----	----	----	----	----	26.6	3.35	23.4	3.80	28	3.19	----	----	----	----
3		3	20-40	11.7	7.56	31.7	2.82	26.2	3.4	----	----	29.6	3.02	30.9	2.92	26.6	3.35	----	----	28	3.19	10.5	8.42	56.3	1.63
4		4	40-60	-----	----	31.7	2.82	26.2	3.4	----	----	29.6	3.02	30.9	2.92	26.6	3.35	----	----	28	3.19	10.5	8.42	56.3	1.63
5	Hole -2	1	Surface	11.7	7.56	31.7	2.82	----	----	29.4	3.03	----	----	----	----	26.6	3.35	27.4	3.25	27.8	3.21	10.5	8.42	56.3	1.63
6		2	1-10	11.7	7.56	31.7	2.82	----	----	29.4	3.03	----	----	----	----	26.6	3.35	27.4	3.25	27.9	3.20	10.5	8.42	----	----
7		3	10-25	11.7	7.56	31.7	2.82	26.2	3.4	----	----	29.8	3.00	30.9	2.92	26.6	3.35	27.4	3.25	27.9	3.20	10.5	8.42	56.3	1.63
8		4	25-40	----	----	31.7	2.82	26.2	3.4	----	----	29.8	3.00	30.9	2.92	26.6	3.35	27.4	3.25	28	3.19	10.5	8.42	56.3	1.63
9		5	40-75	----	----	31.7	2.82	26.2	3.4	29.4	3.03	29.8	3.00	----	----	26.6	3.35	----	----	27.9	3.20	10.5	8.42	56.3	1.63
10	Hole -3	1	Surface	11.7	7.56	31.7	2.82	----	----	29.4	3.03	----	----	----	----	----	----	23.4	3.80	----	----	----	----	----	----
11		2	1-15	11.7	7.56	31.7	2.82	26.2	3.4	----	----	29.8	3.00	----	----	26.6	3.35	27.4	3.25	27.9	3.20	10.5	8.42	----	----
12		3	15-30	----	----	31.7	2.82	26.2	3.4	----	----	29.8	3.00	----	----	26.6	3.35	27.4	3.25	27.8	3.21	10.5	8.42	----	----
13		4	30-40	----	----	31.7	2.82	26.2	3.4	----	----	29.8	3.00	30.9	2.92	26.6	3.35	27.4	3.25	27.9	3.20	10.5	8.42	----	----
14	Hole -4	1	Surface	11.7	7.56	31.7	2.82	26.2	3.4	29.4	3.03	29.8	3.00	30.9	2.92	26.6	3.35	27.4	3.25	27.9	3.20	10.5	8.42	56.3	1.63
15		2	2-5	11.7	7.56	31.7	2.82	26.2	3.4	----	----	29.8	3.00	----	----	26.6	3.35	27.4	3.25	27.9	3.20	10.5	8.42	56.3	1.63
16		3	5-10	----	----	31.7	2.82	26.2	3.4	----	----	29.8	3.00	----	----	26.6	3.35	----	----	27.8	3.21	10.5	8.42	56.3	1.63
17		4	10-25	----	----	31.7	2.82	26.2	3.4	----	----	29.8	3.00	----	----	26.6	3.35	----	----	27.9	3.20	10.5	8.42	56.3	1.63
18		5	25-40	----	----	31.7	2.82	26.2	3.4	----	----	29.8	3.00	----	----	26.6	3.35	----	----	27.9	3.20	10.5	8.42	56.3	1.63
19		6	40-50	----	----	31.7	2.82	26.2	3.4	----	----	29.8	3.00	----	----	26.6	3.35	----	----	27.9	3.20	10.5	8.42	56.3	1.63
20		7	50-60	----	----	31.7	2.82	26.2	3.4	----	----	29.8	3.00	----	----	26.6	3.35	----	----	28	3.19	10.5	8.42	56.3	1.63

The given data is based on the tables of key lines in X-ray powder diffraction patterns for minerals after Chen (1977). The first significant reflection is used for identification of the different mineral species present.

Results and Discussion

Bulk Mineralogy

The whole mineral assemblages determined in twenty sabkha samples are shown in Table (2). The relative percentages of mineral constituents were determined according to Tucker (1988). It was known that the progressive evaporation of marine and continental waters drives sabkha pore fluids to gypsum saturation and leads to the precipitation of aragonite and gypsum (Patterson and Kinsman, 1982).

Gypsum occurs in considerable amounts especially in the surface samples and near the surface. Gypsum is present in amounts ranging from 68 to 3% near the surface. However, it disappears at the depth more than 20 cm corresponding to increase in both aragonite and Mg-calcite. While halite occurs with an amount varying between 30% and 4%. Halite generally increases with depth.

Aragonite, Mg- calcite, calcite and dolomite are the carbonate minerals detected in the sabkha deposits. They are arranged in decreasing order of abundance. Aragonite occurs in amount varies between 36% and 9% and is disappeared when gypsum increases. Mg- calcite varies from 12% to 6%, while calcite and dolomite present in small amounts in some samples. The interaction of normal marine brines (rich with Mg solution) with pre-existing calcium carbonate minerals leads to the formation of diagenetic dolomite. Calcian dolomite is considered the recent forming dolomite today due to surface evaporative marine conditions which contains excess calcium (Land, 1985 and Reeder, 1983). Change in the carbonate minerals has been in the studied sabkha sequences. Both the aragonite and Mg-calcite content increases with increasing depth.

TABLE (2) RELATIVE PERCENTAGES OF TOTAL MINERALS IN THE SOUTHERN CORNICHE SABKHA SEDIMENTS

				Evaporite Minerals %		Carbonate Minerals %				Terrigenous Minerals %				
S. No		Samples	Depth(cm)	Gypsum	Halite	Aragonite	Calcite	Mg-Calcite	Dolomite	Quartz	K-Feldspar	Plag-Feldspar	Amphiboles	Pyrite
1		1	Surface	54	19	----	----	----	----	12.00	9.00	6.00	----	----
2	Hole 1	2	1-20	58	4	----	----	----	----	20.00	10.00	8.00	----	----
3		3	20-40	3.00	22	27.00	----	8.00	7.00	13.00	----	11.00	5.00	4.00
4		4	40-60	----	19	26.00	----	8.00	4.00	25.00	----	12.00	3.00	3.00
5		1	Surface	28	30	----	4	----	----	17.00	9.00	8	2	2
6		2	1-10	36	9	----	7	----	----	24.00	7.00	14.00	3.00	----
7	Hole -2	3	10-25	4	18	18.00	----	7.00	13.00	12.00	7.00	11.00	7.00	3.00
8		4	25-40	----	25	21.00	----	12.00	6.00	9.00	16.00	5.00	3.00	3.00
9		5	40-75	----	16	23.00	10	14.00	----	12.00	----	18.00	5.00	2.00
10		1	Surface	68	9	----	11	----	----	----	12.00	----	----	----
11	Hole -3	2	1-15	10.00	9	10.00	----	7.00	----	35.00	7.00	14.00	8.00	----
12		3	15-30	----	13	9.00	----	7.00	----	45.00	5.00	12.00	9.00	----
13		4	30-40	----	9.00	9.00	6	7.00	5.00	39.00	4.00	17.00	10.00	----
14		1	Surface	30.00	13.	19.00	----	6.00	4.00	9.00	3.00	5.00	3.00	2.00
15		2	2-5	6.00	12	28.00	----	9.00	----	17.00	6.00	12.00	8.00	2.00
16		3	5-10	----	18.00	33.00	----	11.00	----	19.00	----	7.00	9.00	3.00
17	Hole -4	4	10-25	----	20.00	36.00	----	11.00	----	16.00	----	9.00	5.00	3.00
18		5	25-40	----	20.00	35.00	----	12.00	----	14.00	----	9.00	5.00	5.00
19		6	40-50	----	24.00	33.00	----	10.00	----	17.00	----	8.00	5.00	3.00
20		7	50-60	----	29.00	23.00	----	11.00	----	14.00	----	11.00	9.00	3.00

TABLE (3) MAJOR AND TRACE ELEMENTS CORRELATED WITH MINERAL GROUPS PRESENT IN THE STUDIED SABKHA DEPOSITS OF SOUTHERN CORNICHE OF JEDDAH

S.No		Samples	Depth(cm)	Evap.	Carb.	Terr.	Ca%	Mg%	Fe%	Mn(ppm)	Cu(ppm)	Zn(ppm)	Pb(ppm)
1	Hole -1	1	Surface	73	0	27	6.26	0.07	0.74	116	8	32	0
2		2	1-20	62	0	38	11.03	0.05	0.38	90	6	19	1
3		3	20-40	25	42	29	12.01	0.85	0.43	99	8	22	3
4		4	40-60	19	38	40	14.84	0.32	0.3	78	5	17	1
5	Hole -2	1	Surface	58	4	36	4.94	0.12	0.98	309	8	39	10
6		2	1-10	45	7	48	9.39	0.16	1.06	285	12	34	17
7		3	10-25	22	38	37	16.25	1.6	0.75	174	13	32	6
8		4	25-40	25	39	33	15.87	1.13	0.41	84	7	21	7
9		5	40-75	16	47	35	13.56	0	0.01	74	2	15	6
10	Hole -3	1	Surface	77	11	12	7.49	0.19	0.29	50	7	12	6
11		2	1-15	19	17	64	15.28	0.31	0.98	285	9	26	9
12		3	15-30	13	16	71	11.04	0.24	1	278	9	25	1
13		4	30-40	9	27	70	9.46	0.22	0.96	282	8	25	3
14	Hole -4	1	Surface	43	29	20	14.13	0.58	0.47	129	6	16	2
15		2	2-5	18	37	43	11.1	0.35	0.35	114	4	12	0
16		3	5-10	18	44	35	13.35	0.35	0.33	85	5	11	0
17		4	10-25	20	47	37	17.14	0.35	0.33	98	4	11	0
18		5	25-40	20	47	28	1.35	0	0.02	104	4	13	0
19		6	40-50	24	43	30	13.01	0.37	0.36	96	5	9	0
20		7	50-60	29	34	34	14.04	0.44	0.52	144	5	15	0
Average concentration in Sabkha - Southern Corniche of Jeddah (present study)							12.13	0.39	0.053	149	7	20	4
Average concentration in nearshore sediments of Southern Corniche of Jeddah (after El-Sayed etal, 2002)							23.75	0.95	0.15	28	4	8	1
Metal concentration in modern marine Sabkha (Sabkha Gavish from east Sinai, 1980)							_	_	_	_	2.10	4.46	1.8

Terrigenous minerals; quartz, plagioclase feldspar, k-feldspar and amphibole are also common in the studied sabkha deposits. Quartz occurs in amounts ranging from 45 to 9% while feldspar (potash and plagioclase) varies from 21% and 7% with the dominance of plagioclase feldspar which can be attributed to the volcanic origin. The considerable amount of terrigenous minerals in these sabkhas is attributed to the strong activity of winds in the southern Corniche of Jeddah.

Authigenic pyrite is recorded in most sabkha samples analyzed and not exceed than 5% indicating an anaerobic environment and high content of organic matter with the bad odur. Pyrite is formed during shallow burial through the reaction between detrital iron (heavy minerals) and hydrogen sulfide produced by the bacterial reduction of interstial dissolved sulfate (Berner, 1970 and Gheith,1999).

Geochemistry of Sabkha Deposits

Concentration of elements Ca, Mg, Fe, Mn, Cu, Zn and Pb have been determined in the sabkha sediments from the Southern Corniche of Jeddah which have been measured by atomic absorption spectrometer after digestion of the samples with HF and HNO_3. The obtained data is listed in Table (3) together with the determined mineral groups present in the analyzed samples. El-Sayed and Basham (2004) found that most of the Fe was held in the residual unavailable form while most of Mn, Cu, Zn and Pb are distributed between the environmentally unstable exchangeable, oxidizable and reducible fractions. Furthermore, these elements are supposed to have greater mobility and may accumulated in high amounts that influence the environmental characteristics.

Ca concentration in sabkha sediments varies between 17.35% and 1.35 with an average value equal to 12.13%. Ca increases with the increasing depth (Table 3). Ca concentrations measured in the nearshore sediments of the Southern Corniche of Jeddah have an average equal to 23.75%, while Mg concentration exhibits low values ranging between 0.05 and 1.6% and average 0.39% less than those determined in the nearshore sediments (Table 3).

Fe occurs in sabkha sediments with low amounts ranging from 0.01 to 1.01% with an average 0.15% similar to that determined in the nearshore sediments (Table 3). Mn is present in values ranging from 309 to 50 ppm with an average equal to 149 ppm generally larger than those found in the nearshore sediments (28 ppm). No peculiar trend is observed with depth.

Cu is generally present with low concentrations varying from 13 to 2 ppm, while Zn occurs with high amounts ranging between 39 and 9 ppm. Pb exhibits low concentrations varying from 17 to 1 ppm, however, Pb is disappeared in hole 4. Above all, it was noticed that concentrations of these elements are generally increase with depth where metals can be associated with organic matter and/or deposited either with carbonates or as sulfides.

One can conclude that Cu, Zn, and Pb have the highest concentration in the sabkha deposits of the Southern Corniche of Jeddah than those reported in the nearshore sediments of the above area (El-Sayed et al, 2002) and those of the Ainai sabkha (Gavish, 1980).

Conclusions

The mineralogical and chemical characteristics of sabkha deposits developed in the supratidal flat sediments and near the lagoons in the Southern Corniche of Jeddah have been achieved through a study of the sedimentary sequences in four holes drilled until 75 cm deep.

The mineral assemblages found in the studied sabkhas are mainly formed of two assemblages: evaporites include; gypsum, halite, aragonite, Mg-calcite, dolomite, and detrital consists of quartz, feldspar, amphibole and finally authigenic pyrite. Gypsum occurs in high concentration near the surface and is disappeared near depth 20 cm accompanying by increasing aragonite. Destruction of gypsum by bacteria under the surface is documented due to the presence of algal mats and formation of H_2S (bad odour) which indirectly causes the formation of pyrite minerals in the sabkha.

Mn, Cu, Zn and Pb concentrations exhibited by sabkha sediments are generally higher than their encountered nearshore sediments.

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